By Skip Cubbedge, N0UEI

The Global Positioning System

A GPS receiver can tell you where you are in the world, anywhere in the world, 24 hours a day, using signals transmitted from satellites.

There's nothing ordinary about a GPS receiver. This is a spread-spectrum microwave receiver, a highly accurate clock and a sophisticated calculator in one package.

The knowledge of where you are is a powerful tool indeed. Imagine being able to locate a favorite fishing hole or campsite, determine your exact grid square on a VHF DXpedition, or continuously relay your position to net control while supporting a civic event or emergency situation. The Global Positioning System (GPS) was designed for the US government to provide a personal positioning system for both military and civilian users. With a hand-held GPS receiver, you can determine your position, bearing, and speed, record waypoints and routes, and use a computer interface to plot your course on a map or to transmit your location to others.

Now that hand-held GPS receivers are becoming affordable to the average person, more and more people (including hams) are taking advantage of this powerful technology. How does GPS work? What do you need to know about GPS to intelligently buy a receiver?

How It Works—The Short Story

The Global Positioning System is comprised of 24 Earth-orbiting satellites (Figure 1), each at an altitude of 12,500 miles and moving in orbits inclined 55° relative to the equator. Each satellite orbits the Earth about once every 12 hours. These GPS satellites are essentially orbiting beacon stations transmitting on 1575.42 MHz.

Down on *terra firma*, a GPS receiver must pick up beacons from at least four GPS satellites to determine your location. As small and attractive as it may be, there is nothing "ordinary" about this device. It's a sensitive *spread-spectrum* receiver, an ultra-accurate clock and a sophisticated mathematical calculator.

In spread-spectrum technology, the transmitted signal is spread over a large bandwidth using a fast-coded "message." (If you tuned across a spread-spectrum signal, you'd probably hear nothing more than an increase in the background noise.) A spread spectrum receiver must synchronize itself to the code message so that it can properly detect the carrier signal. This is no easy task!

Once the GPS receiver is dancing in step with the transmitter, so to speak, the receiver grabs the data it needs from the satellite's signal. To calculate the distance to the bird, the GPS receiver must be able to determine the time difference between the moment the data was sent and the moment it was received—the total time required for the signal to travel between the satellite and the receiver. Since the signal moves at the speed of light (300,000 km/sec) the receiver can easily calculate the distance based on the travel time:

Distance (km) = 300,000 (km/sec) × travel time (sec)

The transmission time is sent by the satellite itself (in what is known as a *nav message*) and the reception time is determined by the receiver's internal clock. For this technique to work with the kind of accuracy we expect, however, the GPS receiver needs a clock as accurate as the satellite clocks. This would require a very expensive clock indeed! To keep GPS receivers affordable for everyone, a fourth unknown quantity, the *clock offset*, is calculated from the range measurements made by the receiver.

The clock offset, when combined with the super-accurate time

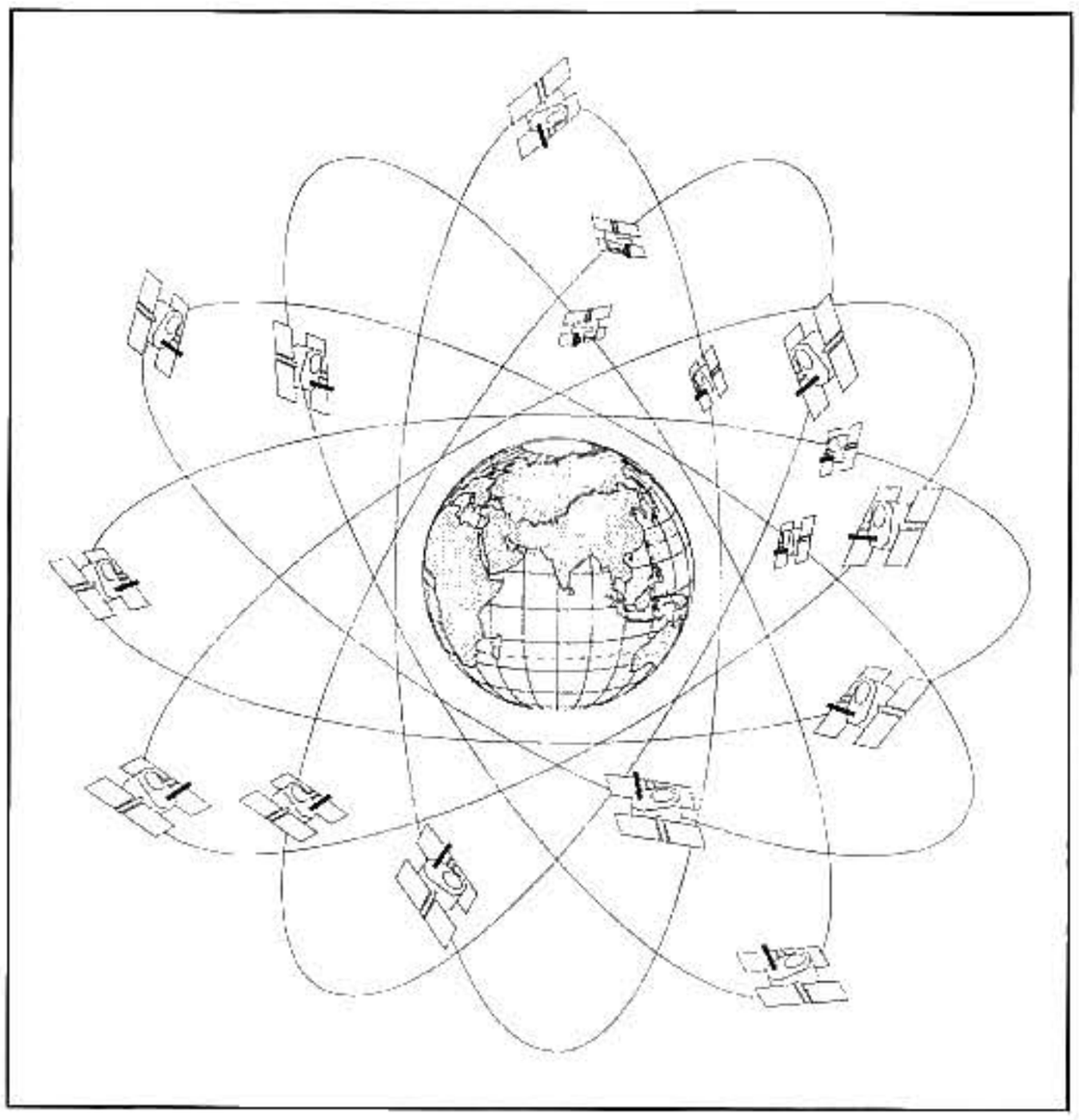


Figure 1—The GPS satellite constellation is a technological marvel, not only because of the satellite complexity itself, but also because of the difficulty of operating such a constellation and keeping the satellites in precisely defined orbits. Because the satellites must transmit very accurate time for the navigation technique to work, each satellite carries highly accurate (and very expensive) cesium- or rubidium-based oscillators as precise time and frequency references.

markers transmitted by the GPS satellites, permits the receiver to display the time to less than one microsecond error, and to perform highly precise ranging. By combining the measured distances between you and the various satellites, the receiver can pinpoint your location anywhere on the globe (see Figure 2).

At a given time, anywhere from five to ten satellites may be in view, depending on the time of day and your location. How does the receiver know which satellites are in view? It keeps an internal almanac of all the GPS satellites, in nonvolatile memory. This almanac is updated continuously via the nav message when the receiver is operating.

Shopping for a GPS Receiver

Great strides have been made in recent years to reduce the size and power requirements of GPS receivers. What was a large rack-mounted chassis 10 years ago now fits in the palm of your hand. Of course, you can choose to "roll your own" GPS receiver, using one of the GPS chip sets or raw circuit boards available (as the AMSAT/NASA team has done for the Phase 3D satellite; see the AMSAT WWW site listed at the end of this article). For the less adventurous, there are now many hand-held GPS receivers that are available to the general public. Average prices of GPS receivers have been plummeting in recent years with some units selling at less than $200. What sorts of features, performance, and capabilities can you expect to find in a hand-held GPS receiver?

The basic position accuracy of a civilian-class GPS receiver is 100 meters. This is because the government has degraded the accuracy available to civilian users through a technique called *selective availability (SA)*. This is about to change, though. By the end of the decade, everyone will have access to much greater GPS accuracy (see the sidebar, "Government Unleashes Full Power of GPS").

The number of satellites tracked simultaneously is an important cost factor. Usually five to eight satellites is plenty for recreational applications. Some receivers will track up to 12 satellites, which means that they'll track all satellites in view, with spare channels available to acquire new satellites. There are two basic types of receiver architecture: *sequential*, in which one channel tracks multiple satellites by dwelling on each satellite for a short time in a scanning mode of operation, and *parallel*, in which each satellite has its own dedicated channel. Parallel tracking is somewhat more robust, and generally costs more than sequential tracking; some receivers employ a combination of both.

Keep in mind that GPS signals travel at least 12000 miles before reaching your receiver. They're quite weak, making your receiving antenna extremely important. Trees, windshields, hats, backpacks and other seemingly minor obstructions can degrade the signals to the point where they're unusable. Unless you are planning to use the unit strictly out in the open, a *removable* antenna becomes a valuable option. Some receivers come with an internal antenna that is not removable, and have no provision for connecting an external antenna. Make sure that your receiver antenna design fits your particular needs.

All hand-held receivers are battery operated, but shop for a unit with an *external* power option if you plan to use the receiver over extended periods of time. Cigarette lighter plug power cables are available for many receivers. Many GPS receivers are waterproofed by sealing the receiver compartment and filling it with nitrogen—this could be crucial if you are using the receiver in a boat or outside in the rain.

Government Unleashes Full Power of GPS

At the present time, civilian GPS receivers are accurate to within 100 meters. Within a decade, however, we'll be able to enjoy the extreme GPS accuracy used by the military. There could be sweeping economic and social consequences as well. The following announcement was released by the White House on March 29, 1996:

WASHINGTON—President Clinton today approved new guidelines for management and use of the US Global Positioning System (GPS).

"The same technology that helped our troops succeed in Desert Storm will bring us safer air travel throughout the world, improved transportation on our roads and highways and faster response to emergencies by rescue vehicles. And it will help America's industries lead the world," President Clinton said.

GPS technology makes it possible for users to determine their position and navigate anywhere in the world GPS is increasingly vital to a wide range of civilian and commercial applications ranging from backpacking and pleasure boating to car navigation, emergency rescue, maritime shipping and international air traffic management. The growing demand from civil, commercial, and scientific users has generated a US commercial GPS equipment and service industry that leads the world.

The new White House policy announces the US Government's intention to terminate the current practice of degrading civil GPS signals within the next decade, providing a better signal for commercial and civilian users of GPS. The policy also reaffirms US commitment to providing basic GPS services, free of direct user fees, for peaceful civil, commercial and scientific users throughout the world.

GPS originally was designed by the Department of Defense as a dual-use system with the primary purpose of enhancing the effectiveness of US and allied military forces. The basic GPS, which consists of a constellation of 24 satellites, their navigation payloads, and associated ground stations, data links, and command and control facilities, is operated and maintained by the Department of Defense. GPS provides a substantial military advantage for US forces and currently is being integrated into virtually every facet of US military operations.

Key to the renewed US commitment to GPS is a recent Air Force statement of support for the President's policy on GPS. According to Dr Sheila E. Widnall, Secretary of the Air Force, the Air Force recognizes the tremendous civil and military aspects of GPS, and fully intends to maintain a 24-satellite constellation for the duration of the program.

The GPS policy review was conducted jointly by the White House Office of Science and Technology Policy and the National Security Council and issued as a directive of the National Science and Technology Council.

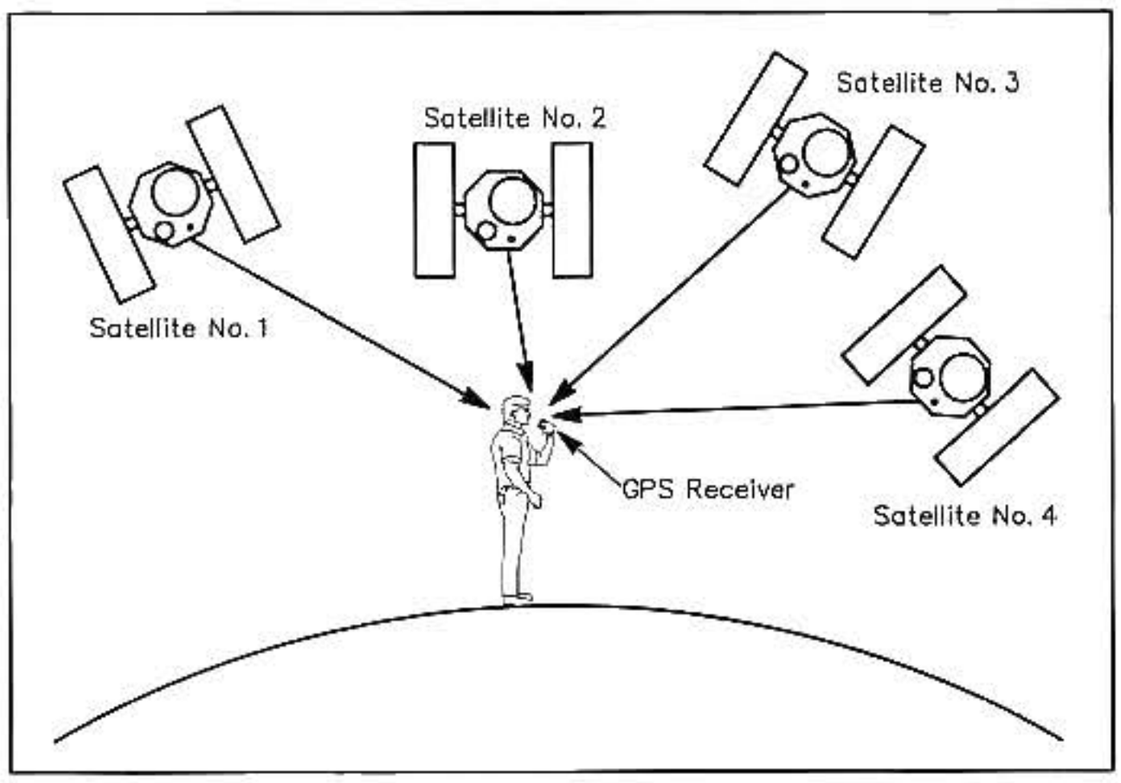


Figure 2—The instant you switch on your GPS receiver, it begins scanning for signals from satellites. Within seconds it acquires the signal from the first satellite (satellite number 1 in this example) and calculates the distance between the satellite and you. It does the same to satellite number 2 soon thereafter. Now it has enough information to calculate a rough latitude and longitude, but more data is still needed. Calculating the distance to satellite number 3 gives the receiver enough information to determine your altitude above sea level. The range calculations to a fourth satellite (satellite number 4) are then added, to determine the clock offset.

Automatic Packet Reporting System

The *Automatic Packet Reporting System (APRS)* was created by Bob Bruninga, WB4APR. *APRS* exploits the ability of a TNC to transmit *beacon* packets that carry short strings of alphanumeric characters. A beacon is an *unconnected* packet. You can think of unconnected packets as "broadcasts." The information is sent to no one in particular and can be received by anyone. An unconnected packet can be relayed through a node or digipeater if you "tell" your TNC to do so.

By taking data from a GPS receiver and incorporating it into beacon packets transmitted by a TNC, you can tell everyone on the network *exactly where that GPS receiver is located.* Any stations equipped with *APRS* software will display the position of the receiver on a computer-generated map. If the receiver moves (let's say it's in an automobile), its position on the map changes with every update

Although *APRS'* mapping capability was developed to display the movement of hand-held GPS receivers, most features evolved from earlier efforts to support real-time packet communication at special events. Any person in the network, upon determining where an object is located, can move his cursor and mark the object on his map screen. This action is then transmitted to all screens in the network, so everyone gains, at a glance, the combined knowledge of all network participants!

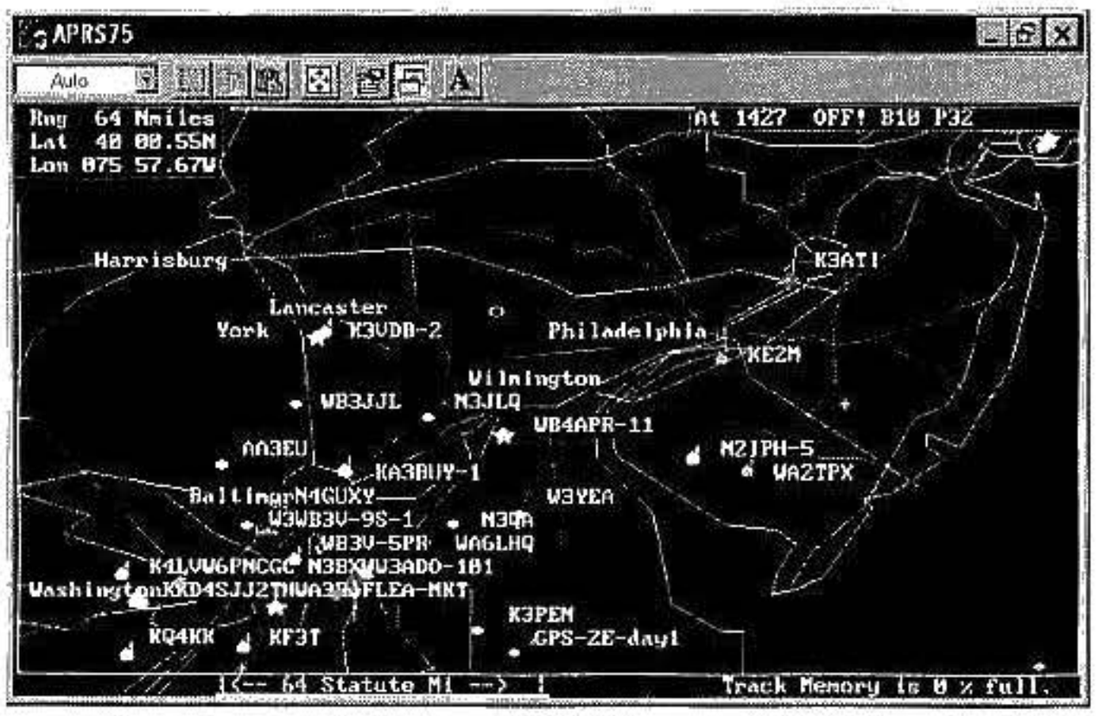
Let's say you're monitoring the movements of rafts during a river race in which each rafter carries a 2-meter FM transceiver, a TNC and a GPS receiver. If your station picks up a transmission from any raft along the river, it will automatically relay the information to everyone else. So, everyone's maps are continually updated with the latest positions of the rafts.

You don't need to own a GPS receiver to enjoy APRS. All you need is the *APRS* software and your normal packet TNC. Just determine your latitude and longitude as best you can. Look it up in an atlas, or borrow a friend's GPS receiver just long enough to determine the position of your station. After you feed the information to the software, your TNC will regularly announce your position to anyone else who is monitoring. You can even use *APRS* to exchange bulletins and enjoy live conversations with others on the network.

Most *APRS* activity is on 2 meters, with 145.79 MHz being the popular frequency. If you do purchase a GPS receiver, you'll need a TNC with *APRS firmware.*

The *APRS* software is distributed as shareware and may be copied for any amateur application. The software includes maps for most areas of the US. You can also edit and add more detail to the maps. *APRS* software is available on many ham-oriented BBSs (including the ARRL BBS at 860-594-0306) as well as various on-line services such as CompuServe. You can grab the latest version of *APRS* for IBM-compatible PCs on the World Wide Web at: **ftp://ftp.tapr.org/tapr/SIG/aprssig/files/dosstuff/DOSaprs/**. If you're a Macintosh user, try **ftp://ftp.tapr.org/tapr/SIG/aprssig/files/macstuff/MacAPRS/**.

If you are planning to use your GPS receiver with the increasingly popular *Automatic Packet Reporting System (APRS)* software (see the sidebar, "Automatic Packet Reporting System"), the receiver *must* have the capability to send position data to your packet TNC. You'll need a receiver with an NMEA 0183 data interface port, which is the standard used by some packet TNC manufacturers as well as the GPS receiver industry. The NMEA data interface can also be connected directly to a computer that is running one of the many popular map database programs. These programs indicate your position on the map, and even drop graphic "bread crumbs" on the street display so that you can track your progress and retrace your steps if necessary.



***APRS* running under *Windows 95*, courtesy of N2IPH from his Web site at http://www.cyberenet.net/~n2iph/bob.htm.**

Most GPS receivers compute bearings and speeds for you, using multiple position measurements made as you are moving along. Receivers vary widely as to how this information is displayed, ranging from alphanumeric display to a graphical representation of a "road" in front of you with a compass "dial" indicating the direction traveled. Most receivers will allow you to store locations as *waypoints*, and to group sequences of waypoints together into *routes*. With waypoints and routes, the receiver can prompt you as to what bearing to take and when to make turns. This information can be displayed either as text or graphically. As many display methods are available as there are manufacturers, so you should shop around for what is most appealing to you.

For Further Information

Want to learn more about the fascinating technology of GPS? There are many excellent sources available, both in written form and on the World Wide Web. You can even buy a receiver directly from some Web advertisers. Some of these sources are listed below:

GPS World—A monthly compendium of popular articles on GPS techniques, issues, and applications.

Global Positioning System: Theory and Applications, Vols. I and II, ed. B. W. Parkinson and J. J. Spilker, AIAA, 1996. A very thorough and complete collection of theoretical, historical, and practical information on GPS

The Global Positioning System, Thomas A. Herring, *Scientific American*, Feb 1996, pp 44-50. A good general article on the technical details as well as some of the social impacts of GPS.

WWW Sites.

http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html. A great source of information, tutorials, and other GPS links.

http://www.amsat.org/amsat/sats/phase3d/gps/. The official AMSAT Phase 3D GPS receiver WWW site.

http://www.nmaa.org/navtech.com. Home page of Navtech GPS Supply, a source for receivers, software, books, and other GPS-related materials.

ftp://aleph.gsfc.nasa.gov/GPS/totally.accurate.clock/. A project by Tom Clark, W3IWI, to use GPS as a means to provide extremely accurate time for amateur applications.

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